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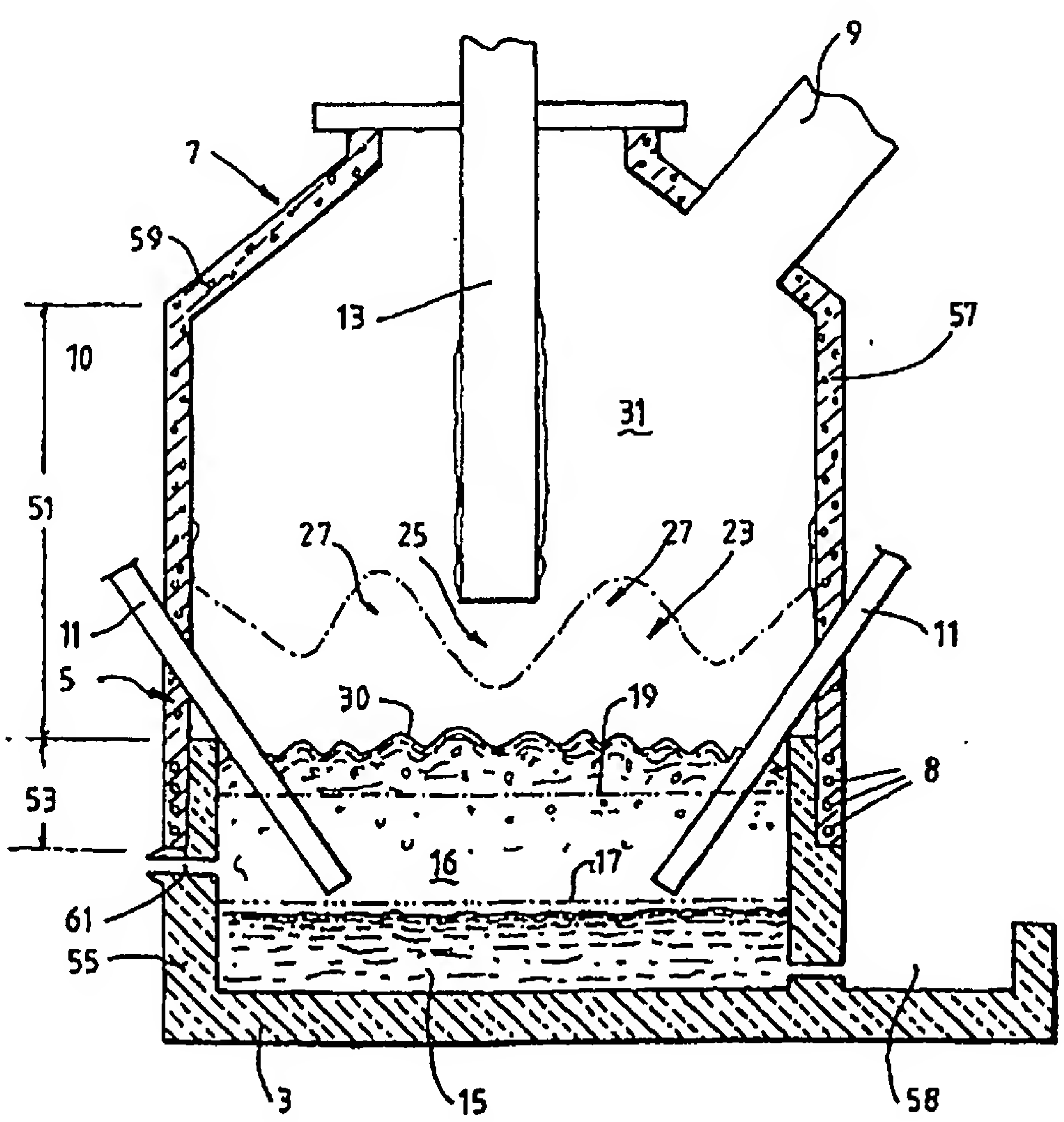
(54) Title: DIRECT SMELTING VESSEL AND DIRECT SMELTING PROCESS

(57) Abstract

A vessel which produces metal from a metalliferous feed material by a direct smelting process is disclosed. The vessel contains a molten bath having a metal layer (15) and a slag layer (16) on the metal layer and has a gas continuous space (31) above the slag layer. The vessel includes a hearth formed of refractory material having a base (3) and sides (55) in contact with the molten metal and side walls (5) which extend upwardly from the sides (55) of the hearth and are in contact with the slag layer and the gas continuous space. The side walls that contact the gas continuous space include water cooled panels (57) and a layer of slag on the panels. The vessel also includes one or more than one lance/tuyere (13) extending downwardly into the vessel and injecting an oxygen-containing gas into the vessel above the metal layer and a plurality of lances/tuyeres (11) injecting at least part of the metalliferous feed material and a carbonaceous material with a carrier gas into the molten bath so as to penetrate the metal layer.



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DIRECT SMELTING VESSEL AND DIRECT SMELTING PROCESS

The present invention relates to a direct smelting vessel for producing molten metal (which term includes metal alloys) from a metalliferous feed material such as ores, partly reduced ores and metal-containing waste streams.

The present invention relates particularly to a vessel that can be used for molten bath-based direct smelting processes.

The present invention also relates to a direct smelting process that operates in the vessel.

The term "smelting" is understood herein to mean thermal processing wherein chemical reactions that reduce metalliferous feed material take place to produce liquid metal.

The term "direct smelting process" is understood herein to mean a process that produces a molten metal directly from a metalliferous feed material, such as iron ore and partly reduced iron ore.

There is a range of known vessels that has been developed to undertake molten bath-based direct smelting processes within a gas/liquid environment of a molten bath.

One known molten bath-based direct smelting process for producing molten iron from iron ore, which is generally referred to as the Romelt process, is based on the use of a large volume, highly agitated slag bath as the medium for smelting top-charged metal oxides to metal and for post-combusting gaseous reaction products and transferring the heat as required to continue smelting

metal oxides. The Romelt process includes injection of oxygen enriched air or oxygen into the slag via a lower row of tuyeres to provide slag agitation and injection of oxygen into the slag via an upper row of tuyeres to promote post-combustion. In the Romelt process the metal layer is not an important reaction medium.

Another known group of molten bath-based direct smelting processes for producing molten iron from iron ore that is also slag-based is generally described as "deep slag" processes. These processes, such as DIOS and AISI processes, are based on forming a deep layer of slag with 3 regions, namely: an upper region for post-combusting reaction gases with injected oxygen; a lower region for smelting metal oxides to metal; and an intermediate region which separates the upper and lower regions. As with the Romelt process, the metal layer below the slag layer is not an important reaction medium.

Another known bath-based direct smelting process for producing molten iron from iron ore, which relies on a molten metal layer as a reaction medium, and is generally referred to as the HIsmelt process, is described in International application PCT/AU96/00197 (WO 96/31627) in the name of the applicant.

The HIsmelt process as described in the International application comprises:

(a) forming a bath of molten iron and slag in a vessel;

(b) injecting into the bath:

(i) metalliferous feed material, typically metal oxides; and

(ii) a solid carbonaceous material, typically coal, which acts as a reductant of the metal oxides and a source of energy; and

(c) smelting the metalliferous feed material to metal in the metal layer.

The HIsmelt process also comprises post-combusting reaction gases, such as CO and H_2, released from the bath in the space above the bath with injected oxygen-containing gas and transferring the heat generated by the post-combustion to the bath to contribute to the thermal energy required to smelt the metalliferous feed materials.

The HIsmelt process also comprises forming a transition zone above the nominal quiescent surface of the bath in which there is a favourable mass of ascending and thereafter descending droplets or splashes or streams of molten metal and/or slag which provide an effective medium to transfer to the bath the thermal energy generated by post-combusting reaction gases above the bath.

There are significant issues involved in constructing vessels that can contain the above-described direct smelting processes.

More particularly, for economic and safety reasons it is important that the vessels contain the direct smelting processes with minimal heat loss and be capable of withstanding the erosive/corrosive conditions that are a characteristic of the processes over long term operating campaigns.

Process containment must also be combined with means to inject and to mix reactants to form and maintain different zones in the vessels and to separate products of

the processes.

Process chemistry of direct smelting processes generally requires a region of low oxygen potential to smelt metalliferous feed material and a region of high oxygen potential to combust hydrogen and carbon monoxide to obtain combustion energy. As a consequence, typically, there are wide variations in temperature and chemical composition throughout the vessels that contain direct smelting processes which place different demands on the design of vessels.

Some planned and tested direct smelting vessels include an outer steel shell and an internal lining of a refractory material, typically in the form of bricks and/or castables. It is known to use bricks of different composition and physical properties in different sections of the vessels to maximise resistance to thermal and chemical attack and erosion.

For example, refractory bricks in the base of the vessels are usually exposed to molten material that is predominantly metal whereas the refractory bricks in the mid-section of the side walls of the vessels are usually exposed to molten material that is predominantly slag and to gaseous reactants such as CO, H_2, CO_2 and H_2O. The bricks exposed to molten metal and the bricks exposed to molten slag require different chemical properties to resist chemical attack by metal and slag.

Moreover, in the case of vessels that operate slag-based direct smelting processes, such as the Romelt, DIOS, and AISI process, typically the slag region is agitated and the metal region is relatively undisturbed (compared with the HIsmelt process). As a consequence, the bricks exposed to the slag region require physical properties to resist erosion due to contact with agitated

slag.

Furthermore, in the case of vessels that operate metal bath-based direct smelting processes, such as the HIsmelt process, typically the metal region is also agitated. As a consequence, the bricks exposed to this region require physical properties to resist erosion due to washing action of metal against the bricks.

Furthermore, in general terms, post-combustion of reaction gases generates high temperatures of the order of 2000°C or higher and, as a consequence, the bricks exposed to the top space/transition zone/slag region in which post-combustion occurs require physical and chemical properties to withstand high temperatures.

In practice, linings of refractory materials have not been an unqualified success for a number of developing direct smelting processes.

There have been proposals to enhance the performance of refractory material linings by water cooling the linings. One particular proposal is described in Australian patent application 692405 in the name of Steel Technology Corporation in the context of a vessel for carrying out the AISI deep slag process. There have also been a limited number of proposals to use water cooled panels in place of refractory materials. On the basis of information available to the applicant these proposals have resulted in excessive heat losses and have been unsuccessful on this basis.

An object of the present invention is to provide an improved direct smelting vessel.

Another object of the present invention is to provide an improved direct smelting process that operates

in the vessel.

The present invention achieves these objects by constructing a direct smelting vessel with water cooled panels in the side walls and the roof of the vessel and injection lances for oxygen-containing gas and injection lances for solids material extending into the vessel which make it possible to operate a direct smelting process in the vessel which builds-up and thereafter maintains on the water cooled panels a layer of slag which acts as an effective thermal insulation such that there are reduced heat losses from the vessel.

According to the present invention there is provided a vessel which produces metal from a metalliferous feed material by a direct smelting process, which vessel contains a molten bath having a metal layer and a slag layer on the metal layer and has a gas continuous space above the slag layer, which vessel includes:

(a) a hearth formed of refractory materiel having a base and sides in contact with the molten metal;

(b) side walls which extend upwardly from the sides of the hearth and are in contact with the slag layer and the gas continuous space, wherein the side walls that contact the gas continuous space include water cooled panels and a layer of slag on the panels;

(c) one or more than one lance/tuyere extending downwardly into the vessel and injecting an oxygen-containing gas into the vessel above the metal layer;

(d) a plurality of lances/tuyeres injecting at

least part of the metalliferous feed material and a carbonaceous material with a carrier gas into the molten bath so as to penetrate the metal layer; and

(e) a means for tapping molten metal and slag from the vessel.

Preferably the direct smelting process operates with heat losses of less than 150 kW/m^2 of exposed panel area of the water cooled panels under normal operating conditions.

The term "normal operating conditions" is understood herein to mean periods when the process is stable and excludes periods where there are likely to be high peak flux loads, such as during start-up.

Preferably, the direct smelting process operates with heat losses of less than 100 kW/m^2 of exposed panel area of the water cooled panels under normal operating conditions.

More preferably the direct smelting process operates with heat losses of less than 90 kW/m^2 of exposed panel area of the water cooled panels under normal operating conditions.

The water cooled panels may be of any suitable configuration.

One preferred construction of water cooled panel includes an inner (in relation to the inside of the vessel) water cooling pipe that has a serpentine shape, a water inlet at one end, and a water outlet at the other end.

Preferably the panel further includes an outer

water cooling pipe that has a serpentine shape, a water inlet at one end, and a water outlet at the other end.

In one alternative construction the inner and outer water cooling pipes of a panel are interconnected and include a single inlet and a single outlet.

Preferably the panel further includes a refractory material rammed or gunned in the spaces of the panel that are not occupied by the pipes. It is believed that in practice this refractory material is worn away progressively during the life of the vessel, with the start-up phase and process perturbations of the direct smelting process causing the most significant wear. The erosion of the rammed or gunned refractory material can cause at least partial exposure of the inner water cooling pipe.

Preferably the rammed or gunned refractory material forms an inner surface of the panel.

The panel may include a support plate which forms an outwardly facing surface of the panel.

The water cooling pipes and the support plate may be constructed from any suitable materials. Suitable materials for the pipes include steel and copper. Steel is an example of a suitable material for the support plate.

Preferably each water cooling pipe includes parallel, horizontal sections that extend across the width of the panel and interconnect curved sections at the ends of the straight sections.

Preferably the outer water cooling pipe is displaced from the inner water cooling pipe so that the horizontal sections of the outer water cooling pipe are not

immediately behind the horizontal sections of the inner water cooling pipe. As a consequence, at least a substantial part of an inner surface of the panel that is exposed to the inside of the vessel is subject to water cooling by water flowing through the inner and outer pipes.

Preferably the inner exposed surface of the panel includes a surface finish, such as a ripple or waffle surface, that increases the exposed surface area of the panel and promotes attachment of frozen slag onto the face.

Preferably the panel includes members, such as pins and cups, which project inwardly from the exposed face of the panel and promote formation and growth of frozen slag on the panel and assist the slag to key to the panel.

Preferably the side walls that contact the slag layer include water cooled panels, a lining of refractory and a layer of slag on the lining.

Preferably the refractory lining is formed from the refractory bricks.

Preferably the vessel contains a transition zone formed by ascending and thereafter descending splashes, droplets and streams of molten material in the gas continuous space above the slag layer with some of these splashes, droplets and streams being contiguous with the side walls of the vessel and depositing molten slag on the side walls.

Preferably the water cooled panels contact the transition zone.

Preferably heat extraction via the water cooled panels is sufficient to build-up and maintain a layer of slag on the water cooled panels that contact the transition

zone.

Preferably splashes, droplets and streams of molten material extend above the transition zone and contact the side walls of the vessel above the transition zone.

More preferably heat extraction via the water cooled panels is sufficient to build-up and maintain a layer of slag on the panels that are above the transition zone.

Preferably, the vessel includes a roof that is in contact with the gas continuous space and includes water cooled panels.

Preferably splashes, droplets and streams of molten material extend above the transition zone and contact the roof.

More preferably the heat extraction via the water cooled panels is sufficient to build up and maintain a layer of slag on the panels.

The slag may form as a "wet" layer or a "dry" layer on the water cooled panels. A "wet" layer includes a frozen layer that adheres to the inner surface of the panels, a semi-solid (mush) layer, and an outer liquid film. A "dry" layer is one in which substantially all of the slag is frozen.

Preferably the base and sides of the hearth include a lining of refractory material in contact with the molten bath.

Preferably the refractory lining is formed from refractory bricks.

Preferably the solid material injection lances/tuyeres extend downwardly and inwardly into the vessel at an angle of 30-60°.

Preferably the ends of the solid material injection lances/tuyeres are above the level of the molten metal.

Preferably injection of solid material via the solid material lances/tuyeres causes upward movement of splashes, droplets and streams of molten material into the gas continuous space.

Preferably the one or more than one lance/tuyere which inject the oxygen-containing gas is positioned to inject the oxygen-containing gas into the transition zone to post-combust reaction gases carbon monoxide and hydrogen in the transition zone.

Preferably the tapping means includes a forehearth which enables continuous discharge of molten metal from the vessel.

According to the present invention there is also provided a direct smelting process for producing metals from a metalliferous feed material in the vessel described in the preceding paragraphs, which process includes the steps of:

(a) forming a molten bath having a metal layer and a slag layer on the metal layer;

(b) injecting at least part of the metalliferous feed material and a solid carbonaceous material with a carrier gas into the molten bath via a plurality of lances/tuyeres and

smelting the metalliferous material in the metal layer, whereby the solids injection causes gas flow from the metal layer which entrains molten material in the metal layer and carries the molten material upwardly as splashes, droplets and streams and forms a transition zone in a gas continuous space in the vessel above the slag layer, whereby splashes, droplets and streams of molten material contact the side walls of the vessel and form a protective layer of slag;

(c) injecting an oxygen-containing gas into the vessel via one or more than one lance/tuyere and post-combusting reaction gases released from the molten bath whereby ascending and thereafter descending splashes, droplets and streams of molten material facilitate heat transfer to the molten bath; and

(d) controlling solid injection and/or oxygen-containing gas injection and/or water flow rate through the water cooled panels so that the heat loss via the water cooled panels is less than 150 kW/m^2 of panel area exposed to the inside of the vessel under normal operating conditions.

Preferably the heat loss via the water cooled panels is less than 100 kW/m^2 of panel area exposed to the inside of the vessel under normal operating conditions.

More preferably the heat loss via the water cooled panels is less than 90 kW/m^2 of panel area exposed to the inside of the vessel under normal operating conditions.

The present invention is described further by way of example with reference to the accompanying drawings of which:

Figure 1 is a vertical section through a metallurgical vessel illustrating in schematic form a preferred embodiment of the present invention;

Figure 2 is a more detailed view of the left side of the vessel shown in Figure 1; and

Figure 3 is a front elevation illustrating the arrangement of water cooling pipes of a number of water cooled panels in the cylindrical barrel of the vessel shown in Figures 1 and 2.

The following description is in the context of direct smelting iron ore to produce molten iron and it is understood that the present invention is not limited to this application and is applicable to any suitable metallic ores and concentrates and other metalliferous feed material - including partially reduced metallic ores and metal containing waste streams.

The vessel shown in the figures has a hearth that includes a base 3 and sides 55 formed from refractory bricks; side walls 5 which form a generally cylindrical barrel extending upwardly from the sides 55 of the hearth and which include an upper barrel section 51 and a lower barrel section 53; a roof 7; an outlet 9 for off-gases; a forehearth 57 for discharging molten metal continuously; and a tap-hole 61 for discharging molten slag periodically.

In use, the vessel contains a molten bath of iron and slag which includes a layer 15 of molten metal and a layer 16 of molten slag on the metal layer 15. The arrow marked by the numeral 17 indicates the position of

quiescent surface of the metal layer 15 and the arrow marked by the numeral 19 indicates the position of the quiescent surface of the slag layer 16. The term "quiescent surface" is understood to mean the surface when there is no injection of gas and solids into the vessel.

The vessel also includes 2 solids injection lances/tuyeres 11 extending downwardly and inwardly at an angle of 30°-60° to the vertical through the side walls 5 and into the slag layer 16. The position of the lances/tuyeres 11 is selected so that the lower ends are above the quiescent surface 17 of the metal layer 15.

In use, iron ore (typically fines), solid carbonaceous material (typically coal), and fluxes (typically lime and magnesia) entrained in a carrier gas (typically N_2) are injected into the metal layer 15 via the lances/tuyeres 11. The momentum of the solid material/carrier gas causes the solid material and the carrier gas to penetrate the metal layer 15. The coal is devolatilised and thereby produces gas in the metal layer 15. Carbon partially dissolves into the metal and partially remains as solid carbon. The iron ore is smelted to metal and the smelting reaction generates carbon monoxide gas. The gases transported into the metal layer 15 and generated via devolatilisation and smelting produce significant buoyancy uplift of molten metal, solid carbon, and slag (drawn into the metal layer 15 as a consequence of solid/gas/injection) from the metal layer 15 which generates an upward movement of splashes, droplets and streams of molten metal and slag, and these splashes, droplets, and streams entrain slag as they move through the slag layer 16.

The buoyancy uplift of molten metal, solid carbon and slag causes substantial agitation in the metal layer 15 and the slag layer 16, with the result that the slag layer

16 expands in volume and has a surface indicated by the arrow 30. The extent of agitation is such that there is reasonably uniform temperature in the metal and the slag regions - typically, 1450-1550°C with a temperature variation of not more than 30°C in each region.

In addition, the upward movement of splashes, droplets and streams of molten material - caused by the buoyancy uplift of molten metal, solid carbon, and slag - extends into the space 31 (the "top space") above the molten bath in the vessel and:

(a) forms a transition zone 23; and

(b) projects some molten material (predominantly slag) beyond the transition zone and onto the part of the upper barrel section 51 of the side walls 5 that is above the transition zone 23 and onto the roof 7.

In general terms, the slag layer 16 is a liquid continuous volume, with gas bubbles therein, and the transition zone 23 is a gas continuous volume with splashes, droplets, and streams of molten material (predominantly slag).

The vessel further includes a lance 13 for injecting an oxygen-containing gas (typically pre-heated oxygen enriched air) which is centrally located and extends vertically downwardly into the vessel. The position of the lance 13 and the gas flow rate through the lance 13 are selected so that the oxygen-containing gas penetrates the central region of the transition zone 23 and maintains an essentially metal/slag free space 25 around the end of the lance 13.

The injection of the oxygen-containing gas via

the lance 13 post-combusts reaction gases CO and H_2 in the transition zone 23 and in the free space 25 around the end of the lance 13 and generates high temperatures of the order of 2000°C or higher in the gas space. The heat is transferred to the ascending and descending splashes, droplets, and streams of molten material in the region of gas injection and the heat is then partially transferred to the metal layer 15 when the metal/slag returns to the metal layer 15.

The free space 25 is important to achieving high levels of post combustion because it enables entrainment of gases in the top space above the transition zone 23 into the end region of the lance 13 and thereby increases exposure of available reaction gases to post combustion.

The combined effect of the position of the lance 13, gas flow rate through the lance 13, and upward movement of splashes, droplets and streams of molten material is to shape the transition zone 23 around the lower region of the lance 13 - generally identified by the numerals 27. This shaped region provides a partial barrier to heat transfer by radiation to the side walls 5.

Moreover, the ascending and descending droplets, splashes and streams of molten material is an effective means of transferring heat from the transition zone 23 to the molten bath with the result that the temperature of the transition zone 23 in the region of the side walls 5 is of the order of 1450°C-1550°C.

In accordance with a preferred embodiment of the present invention the vessel is constructed with reference to the levels of the metal layer 15, the slag layer 16, and the transition zone 23 in the vessel when the process is operating under normal operating conditions and with reference to splashes, droplets and streams of molten

material (predominantly slag) that are projected into the top space 31 above the transition zone 23 when the process is operating, so that:

(a) the hearth and the lower barrel section 53 of the side walls 5 that contact the metal/slag layers 15/16 are formed from bricks of refractory material (indicated by the cross-hatching in the figure) which contact directly the metal and slag in these layers;

(b) at least part of the lower barrel section 53 of the side walls 5 is backed by water cooled panels 8; and

(c) the part of the upper barrel section 51 of the side walls 5 that contact the transition zone 23, the remainder of the upper barrel section 51 that is above the transition zone 23, and the roof 7 are formed from water cooled panels 57, 59.

Each water cooled panel 8, 57, 59 (not shown) in the upper barrel section 51 of the side walls 5 has parallel upper and lower edges and parallel side edges and is curved so as to define a section of the cylindrical barrel. As can best be seen in Figures 2 and 3, each panel 57,59 includes an inner water cooling pipe 63 and an outer water cooling pipe 65. The pipes 63,65 are formed into a serpentine configuration with parallel horizontal sections interconnected by curved sections. The pipes 63,65 further include water inlets/water outlets 69. The pipes 63,65 are displaced vertically so that the horizontal sections of the outer pipe 65 are not immediately behind the horizontal sections of the inner pipe 63 when viewed from an exposed

face of the panel, ie the face that is exposed to the interior of the vessel. Each panel 63,65 further includes a rammed or gunned refractory material which fills the spaces between the adjacent horizontal sections of each pipe 63,65 and between the pipes 63,65 and forms an inner face of the panel. Each panel further includes a support plate 67 which forms an outer surface of the panel.

The water inlets/water outlets 69 of the pipes are connected to a water supply circuit (not shown) which circulates water at high flow rate through the pipes.

In use, the water flow rate through the water cooled panels 57, 59, the solids/carrier gas flow rate via the lances/tuyeres 11, and the oxygen-containing gas flow rate via the lance 13 are controlled so that there is sufficient slag contacting the panels and sufficient heat extraction from the panels to build-up and maintain a layer of frozen slag on the panels. The slag layer forms an effective thermal barrier which thereafter minimises heat loss to below 150 kW/m^2 from the side walls 5 and the roof 7 of the vessel under normal operating conditions of the process.

In extensive pilot plant work carried out by the applicant the applicant has recorded significantly lower heat losses than have been reported with other vessels.

The pilot plant work referred to above was carried out as a series of extended campaigns by the applicant at its pilot plant at Kwinana, Western Australia.

The pilot plant work was carried out with the vessel shown in the figure and described above and in accordance with the process conditions described above.

The pilot plant work evaluated the vessel and

investigated the process under a wide range of different:

(a) feed materials;

(b) solids and gas injection rates;

(c) slag:metal ratios;

(d) operating temperatures; and

(e) apparatus set-ups.

Table 1 below sets out relevant data during typical start-up and stable operating conditions of the pilot plant work.

		START UP	STABLE OPERATION
Bath Temperature	(°C)	1450	1450
Operating Pressure	(bar g)	0.5	0.5
HAB Air	(kNm^3/h)	26.0	26.0
Oxygen in HAB	(%)	20.5	20.5
HAB Temperature	(C)	1200	1200
DSO Ore	(t/h)	5.9	9.7
Coal	(t/h)	5.4	6.1
Calcined Flux	(t/h)	1.0	1.4
Ore Feed Temp	(C)	25.0	25.0
Hot Metal	(t/h)	3.7	6.1
Slag	(t/h)	2.0	2.7
Post Combustion	(%)	60.0	60.0
Offgas Temperature	(C)	1450	1450
Heat Transfer to Bath	(MW)	11.8	17.3
Heat Loss to Panels	(MW)	12.0	8.0
Coal Rate	(kg/thm)	1453	1003

The iron ore was a normal fine direct shipping

ore and contained 64.6% iron, 4.21% SiO_2, and 2.78% Al_2O_3 on a dry basis.

An anthracite coal was used both as a reductant and a source of carbon and hydrogen to combust and supply energy to the process. The coal had a calorific value of 30.7 MJ/kg, an ash content of 10%, and a volatile level of 9.5%. Other characteristics included 79.82% total carbon, 1.8% H_2O, 1.59% N_2, 3.09% O_2, and 3.09% H_2.

The process was operated to maintain a slag basicity of 1.3 (CaO/SiO_2 ratio) using a combination of fluxes of lime and magnesia. The magnesia contributed MgO thereby reducing the corrosiveness of the slag to the refractory by maintaining appropriate levels of MgO in the slag.

Under start-up conditions the pilot plant operated with: a hot air blast rate of 26,000 Nm^3/h at 1200°C; a post combustion rate of 60% ((CO_2 + H_2O) / (CO + H_2 + CO_2 + H_2O)); and a feed rate of iron ore fines of 5.9 t/h, a feed rate of coal of 5.4 t/h and a feed rate of flux of 1.0 t/h, all injected as solids using N_2 as a carrier gas. There was little or no slag in the vessel and there was not sufficient opportunity to form a frozen slag layer on the side panels. As a consequence, the cooling water heat loss was relatively high at 12 MW. The pilot plant operated at a production rate of 3.7 t/h of hot metal (4.5 wt%C) and a coal rate of 1450 kg coal/t hot metal produced.

Under stable operating conditions, with control of slag inventory and a frozen slag layer on the water cooling panels forming the side walls 5 and the roof 7, relatively low total water cooling heat losses of 8 MW were recorded. It is noted that this total water cooling heat loss is the sum of water cooling heat losses from the water cooled panels of the side walls 5 and the roof 7 and also

from other water cooled components of the vessel, such as the lances/tuyeres 11 and the lance 13. This total water cooling heat loss equates to less than 150 kW/m^2 of exposed panel surface of the side walls 5 and the roof 7. The reduction of the heat lost to the water cooling system allowed an increased productivity to 6.1 t/h of hot metal. The increased productivity was obtained at the same hot air blast rate and post combustion as at start-up. Solid injection rates were 9.7 t/h of ore fines and 6.1 t/h of coal along with 1.4 t/h of flux. The improved productivity also improved the coal rate to 1000 kg coal/t hot metal achieved.

The initial design of the water cooling panels for the side walls 5 and the roof 7 of the pilot plant vessel were based on experience from EAF and EOF furnace operation. The design heat flux figures were:

Roof:	230 kW/m^2
Upper barrel:	230 kW/m^2
Lower barrel:	290 kW/m^2

The cooling water circuits were designed with a maximum flow rate to achieve a heat flux of 350 kW/m^2.

It was expected prior to commencing pilot plant trials that the water cooling panels that were exposed directly to the interior of the vessel - ie that were not brick lined - would have heat losses of around 250 kW/m^2. However, under stable operating conditions the heat losses were unexpectedly low - as low as 85 and 65 kW/m^2 - particularly on the exposed water cooling panels forming the upper barrel 51 above the transition zone 23 and the roof 7. In the early campaigns where there was minimal wear of the rammed or gunned refractory material of the panels, the heat losses ranged from and averaged:

Roof:	80-170	120 kW/m^2
Upper Barrel:	60-165	95 kW/m^2
Lower Barrel:	40-160	70 kW/m^2

The panels in the lower barrel 53 were partly protected by refractory bricks.

A similar set of data was obtained from a later campaign. The following data from this campaign reflects the impact of increased wear of the rammed or gunned refractory material of the water cooling panels:

Roof:	80-245	145 kW/m^2
Upper Barrel:	75-180	130 kW/m^2
Lower Barrel:	50-170	110 kW/m^2

Many modifications may be made to the preferred embodiment of the vessel described above without departing from the spirit and scope of the present invention.

CLAIMS:

1. A vessel which produces metal from a metalliferous feed material by a direct smelting process, which vessel contains a molten bath having a metal layer and a slag layer on the metal layer and has a gas continuous space above the slag layer, which vessel includes:

(a) a hearth formed of refractory material having a base and sides in contact with the molten metal;

(b) side walls which extend upwardly from the sides of the hearth and are in contact with the slag layer and the gas continuous space, wherein the side walls that contact the gas continuous space include water cooled panels and a layer of slag on the panels;

(c) one or more than one lance/tuyere extending downwardly into the vessel and injecting an oxygen-containing gas into the vessel above the metal layer;

(d) a plurality of lances/tuyeres injecting at least part of the metalliferous feed material and a carbonaceous material with a carrier gas into the molten bath so as to penetrate the metal layer; and

(e) a means for tapping molten metal and slag from the vessel.

2. The vessel defined in claim 1 further includes a roof that is in contact with the gas continuous space and the roof includes water cooled panels and a layer

of slag on the panels.

3. The vessel defined in claim 1 or claim 2 wherein each water cooled panel includes an inner (in relation to the inside of the vessel) water cooling pipe that has a serpentine shape, a water inlet at one end, and a water outlet at the other end.

4. The vessel defined in claim 3 wherein each water cooled panel further includes an outer water cooling pipe that has a serpentine shape, a water inlet at one end, and a water outlet at the other end.

5. The vessel defined in claim 4 wherein each water cooled panel further includes a refractory material rammed or gunned in the spaces of the panel that are not occupied by the pipes.

6. The vessel defined in claim 4 or claim 5 wherein each of the inner and the outer water cooling pipes includes parallel, horizontal sections that extend across the width of the panel and curved sections that interconnect the ends of the horizontal sections.

7. The vessel defined in claim 6 wherein the outer water cooling pipe is displaced from the inner water cooling pipe so that the horizontal sections of the outer water cooling pipe are not immediately behind the horizontal sections of the inner water cooling pipe.

8. The vessel defined in any one of the preceding claims wherein an inner (in relation to the inside of the vessel) exposed surface of each water cooling panel includes a surface finish, such as a ripple or waffle surface, that increases the exposed surface area of the panel and promotes attachment of frozen slag onto the surface.

9. The vessel defined in any one of the preceding claims wherein each water cooling panel includes members, such as pins and cups, which project inwardly from an inner exposed face of the panel and promote formation and growth of frozen slag on the panel.

10. The vessel defined in any one of the preceding claims wherein at least a section of the side walls that contact the slag layer include water cooled panels, a lining of refractory material positioned inwardly of the panels, and a layer of slag on the lining.

11. The vessel defined in any one of the preceding claims contains a transition zone formed by ascending and thereafter descending splashes, droplets and streams of molten material in the gas continuous space above the slag layer with some of these splashes, droplets and streams being contiguous with the side walls of the vessel and deposit molten slag on the side walls.

12. The vessel defined in claim 11 wherein the side walls include water cooled panels that contact the transition zone.

13. The vessel defined in claim 12 wherein heat extraction via the water cooled panels is sufficient to build-up and maintain a layer of slag on the water cooled panels that contact the transition zone.

14. The vessel defined in any one of claims 11 to 13 wherein the side walls include water cooled panels that are above the transition zone.

15. The vessel defined in claim 14 wherein heat extraction via the water cooled panels is sufficient to build-up and maintain a layer of slag on the panels that

are above the transition zone.

16. The vessel defined in any one of the preceding claims wherein the solid material injection lances/tuyeres extend downwardly and inwardly into the vessel at an angle of 30-60° to the vertical.

17. The vessel defined in any one of the preceding claims wherein lower ends of the solid material injection lances/tuyeres are above the level of the molten metal.

18. The vessel defined in any one of claims 11 to 15 wherein injection of solid material via the solid material injection lances/tuyeres causes upward movement of splashes, droplets and streams of molten material into the gas continuous space.

19. The vessel defined in any one of claims 11 to 15 and 18 wherein the one or more than one lance/tuyere which inject the oxygen-containing gas is positioned to inject the oxygen-containing gas into the transition zone to post-combust reaction gases carbon monoxide and hydrogen in the transition zone.

20. The vessel defined in any one of the preceding claims wherein the tapping means includes a forehearth which enables continuous discharge of molten metal from the vessel.

21. A direct smelting process for producing metals from a metalliferous feed material in the vessel defined in any one of the preceding claims, which process includes the steps of:

(a) forming a molten bath having a metal layer and a slag layer on the metal layer;

(b) injecting at least part of the metalliferous feed material and a solid carbonaceous material with a carrier gas into the molten bath via a plurality of lances/tuyeres and smelting the metalliferous material in the metal layer, whereby the solids injection causes gas flow from the metal layer which entrains molten material in the metal layer and carries the molten material upwardly as splashes, droplets and streams and forms a transition zone in a gas continuous space in the vessel above the slag layer, whereby splashes, droplets and streams of molten material contact the side walls of the vessel and form a protective layer of slag;

(c) injecting an oxygen-containing gas into the vessel via one or more than one lance/tuyere and post-combusting reaction gases released from the molten bath whereby ascending and thereafter descending splashes, droplets and streams of molten material facilitate heat transfer to the molten bath; and

(d) controlling solids injection and/or oxygen-containing gas injection and/or water flow rate through the water cooled panels so that the heat loss via the water cooled panels is less than 150 kW/m^2 of panel area exposed to the inside of the vessel under normal operating conditions.

22. The process defined in claim 21 wherein the heat loss via the water cooled panels is less than 100 kW/m^2 of panel area exposed to the inside of the vessel under normal operating conditions.

23. The process defined in claim 22 wherein the heat loss via the water cooled panels is less than 90 kW/m^2 of panel area exposed to the inside of the vessel under normal operating conditions.

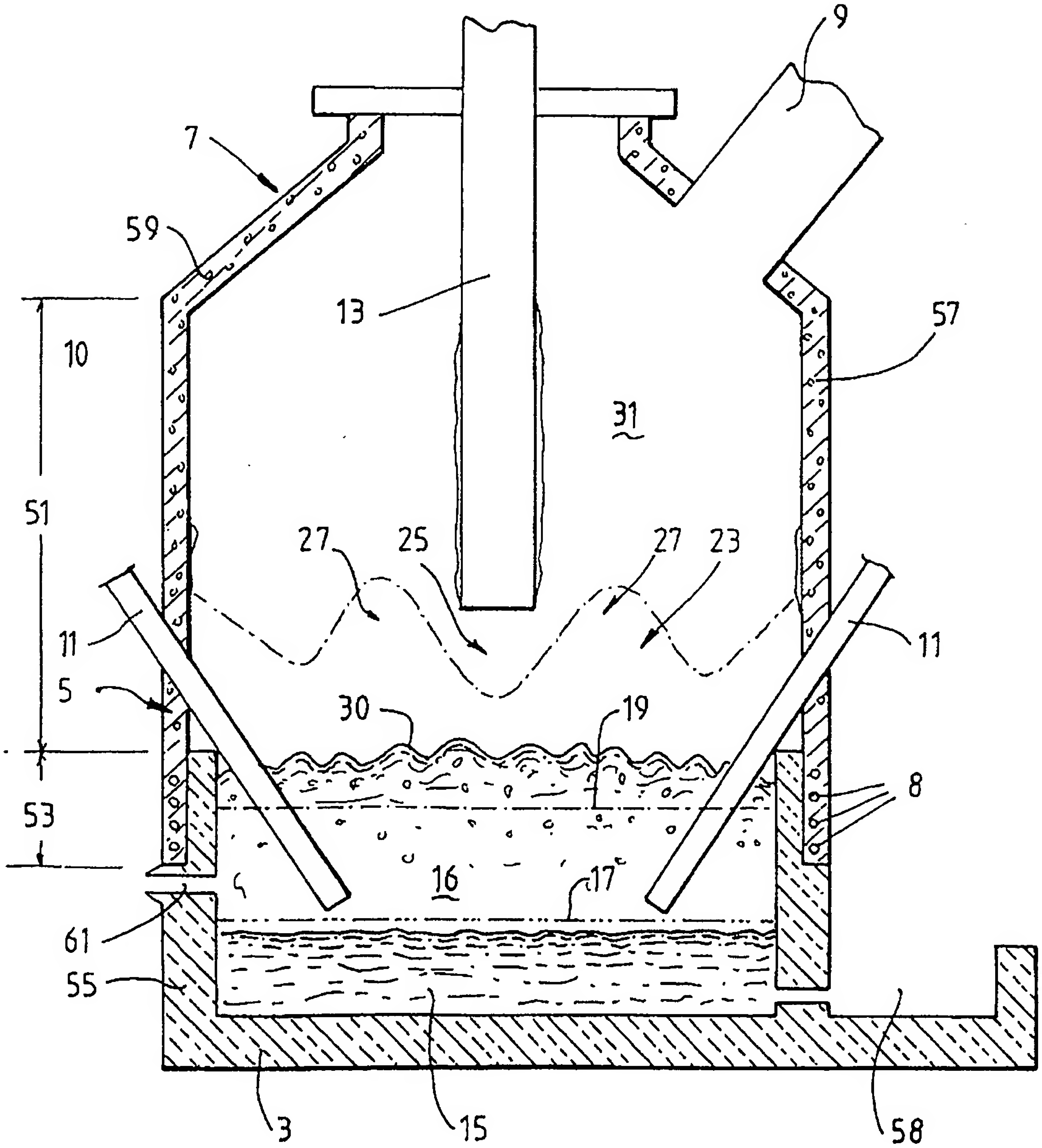

FIG. 1.

FIG. 2.

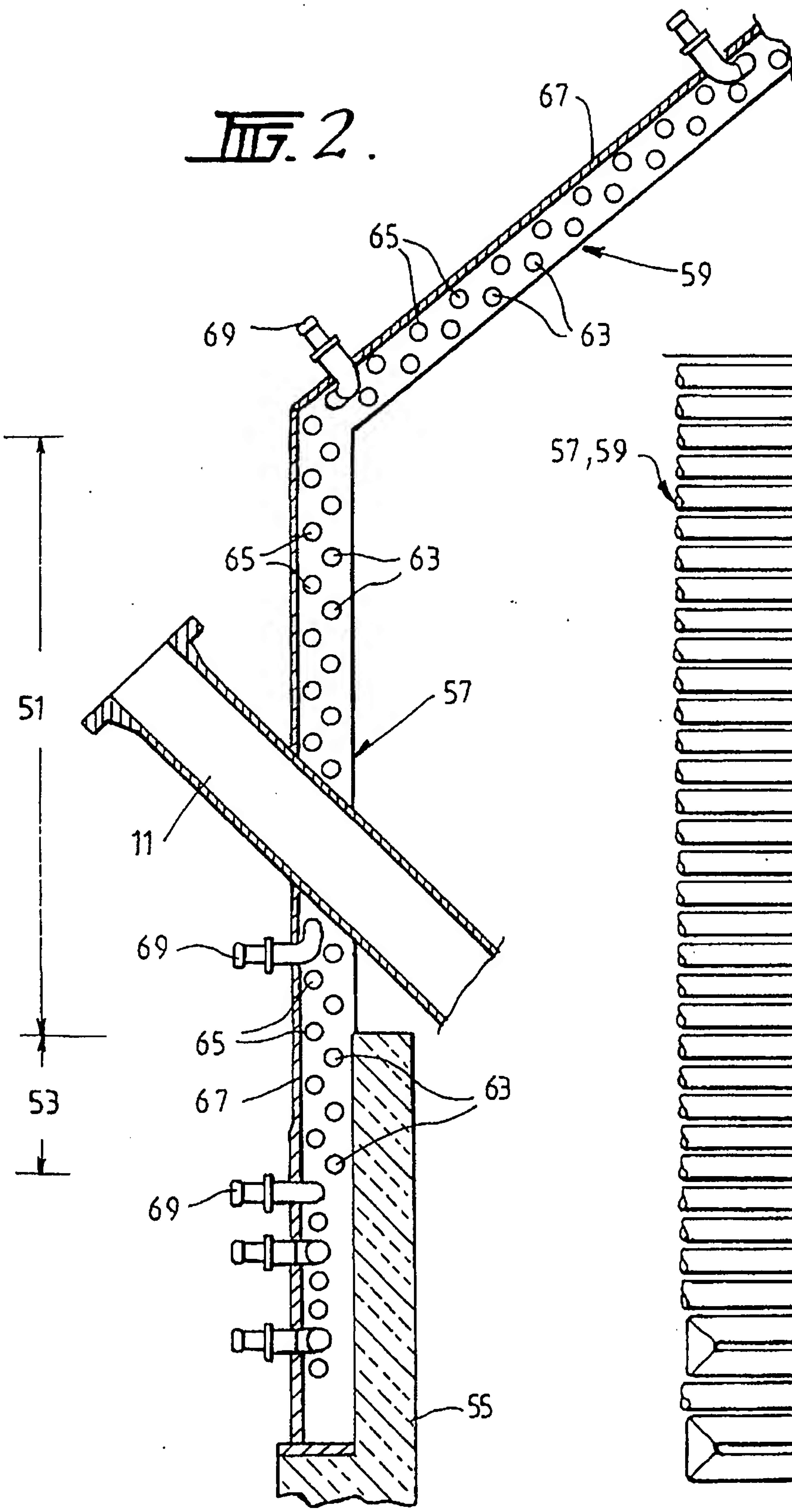
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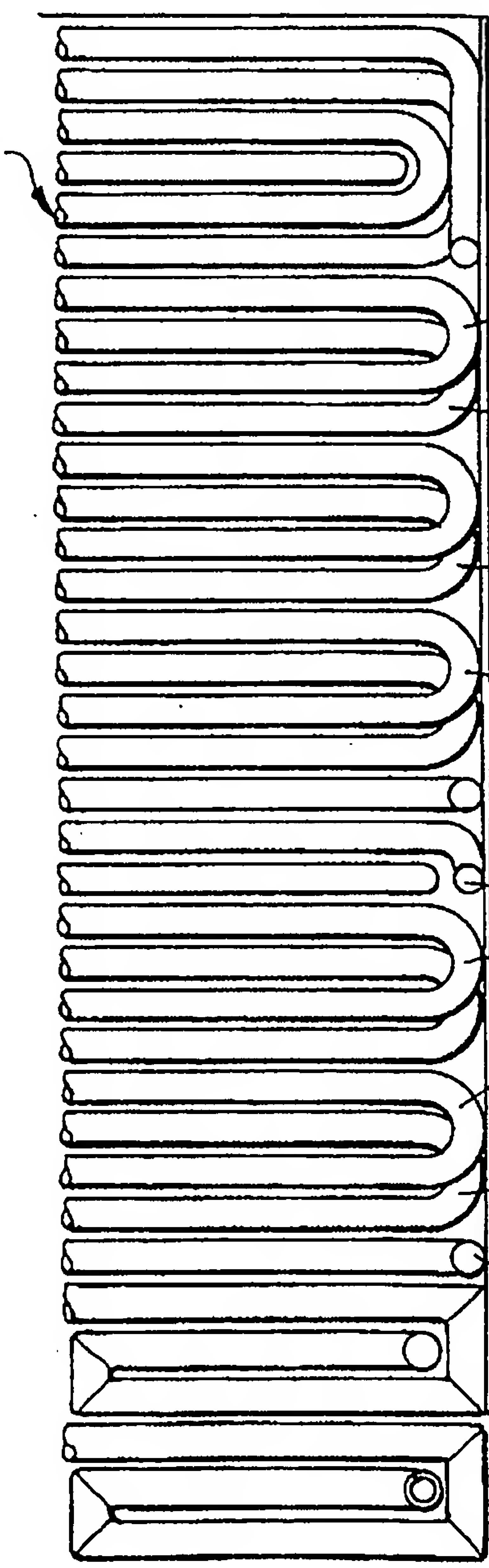
FIG. 3.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INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU 99/00537

A. CLASSIFICATION OF SUBJECT MATTER

Int Cl^{6}: C21B 11/00, 11/08, 13/00, 13/10, C22B 5/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC^{6} As above

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU: IPC As above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Derwent On-line IPC^{6} As above and Keywords lanc: tuyere: blow: top: above down: cool: water.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO, A, 94/19497 (A. Ahlstrom Corporation), 1 September 1994 Page 1, lines 3-15, 30-39; page 2; page 3; Claims 1, 6; Figure.	1-23
Y	WO, A, 96/31627 (Technological Resources Pty. Ltd), 10 October 1996 Page 1, lines 8-22; page 6, lines 7-24; Claims 1, 13; Fig 1, 2.	1-23

[X] Further documents are listed in the continuation of Box C

[X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 July 1999	- 2 AUG 1999

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P, Y	Patent Abstracts of Japan, JP, A, 10-280020 (Nippon Steel Corp.), 20 October 1998 Whole Document	1-23
Y	Patent Abstracts of Japan, C-951, page 24, JP, A, 04-63218 (Kawasaki Heavy Ind. Ltd), 28 February 1992 Whole Document	1-23
Y	Patent Abstracts of Japan, C-627, page 109, JP, A, 01-127613 (Kawasaki Steel Corp.) 19 May 1989 Whole Document	1-23

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/AU 99/00537

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
WO	94/19497	AU	58854/94	CA	2156631	CN	1121358
		EP	686204	FI	93027	JP	8506858
		ZA	9400772				
WO	96/31627	AU	51381/96	BR	9604837	CA	2217353
		CN	1181112	EP	819182	JP	11503200
		ZA	9602795				
JP	10280020	NONE					
JP	04063218	NONE					
JP	01127613	NONE					
							END OF ANNEX

≡ EP 0142399

United States Patent [19]

Rollot et al.

[11] Patent Number: 4,669,708

[45] Date of Patent: Jun. 2, 1987

[54] COOLING PLATES FOR BLAST-FURNACES

[75] Inventors: Pierre Rollot, Prouvy; Gerard Pierrat, Sedan; Claude Le Scour, Bray Dunes, all of France

[73] Assignee: Union Siderurgique du Nord et de l'Est de la France, Puteaux, France

[21] Appl. No.: 843,934

[22] Filed: Mar. 24, 1986

Related U.S. Application Data

[63] Continuation of Ser. No. 653,130, Sep. 21, 1984, abandoned.

[30] Foreign Application Priority Data

Sep. 21, 1983 [FR] France 83 15014

[51] Int. Cl.⁴ C21B 7/10

[52] U.S. Cl. .... 266/193; 122/6 B

[58] Field of Search .... 266/193, 194, 190; 373/165; 122/6 A, 6 L, 6 B

[56] References Cited

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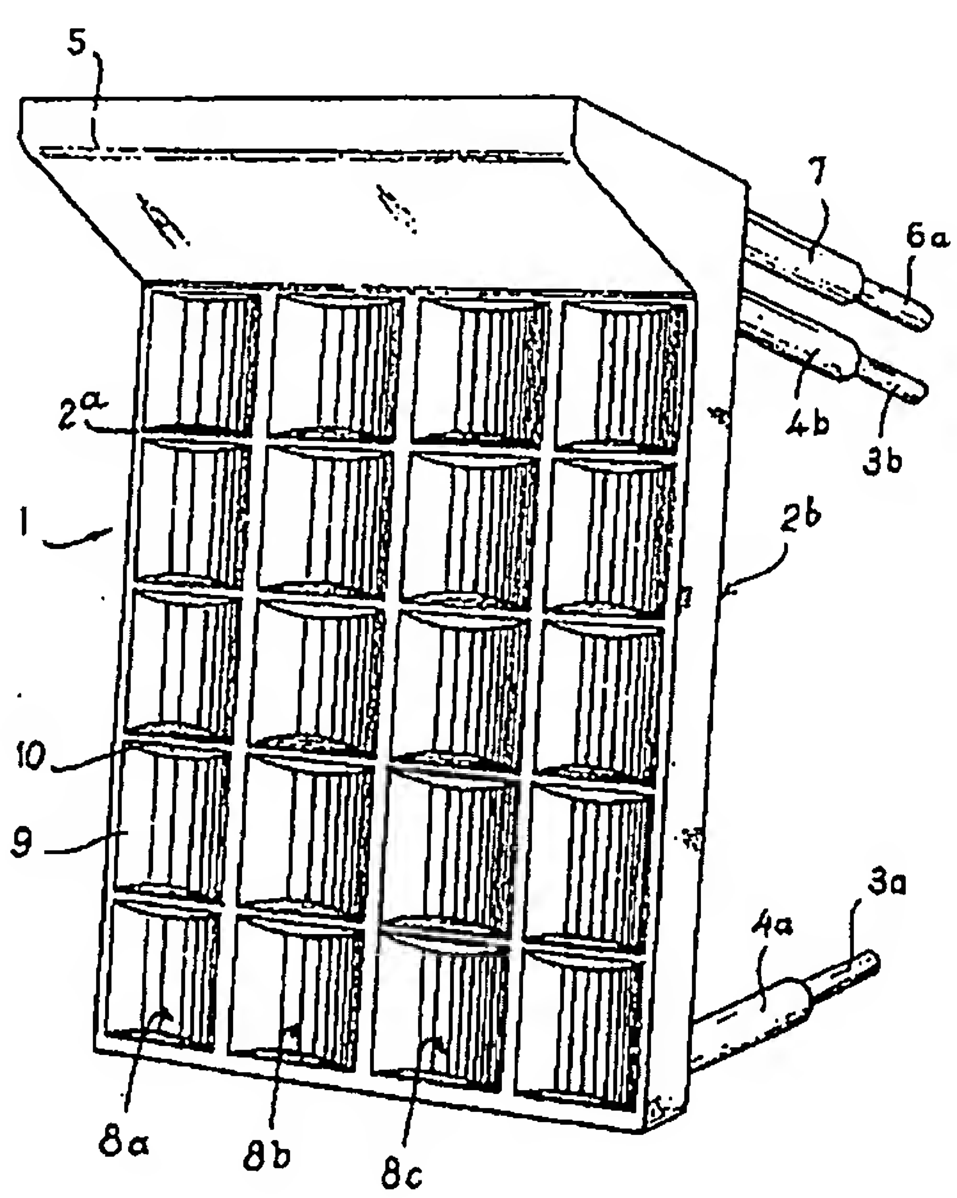
Primary Examiner—L. Dewayne Rutledge
Assistant Examiner—S. Kastler
Attorney, Agent, or Firm—Cushman, Darby & Cushman

[57] ABSTRACT

The cooling plate 1 comprises a cast iron element having substantially the shape of a parallelepiped, embedded longitudinally extending tubes 3; 103 disposed vertically and parallel to one another and extending out of said element on a first side 2*b*; 102*b* of said element, and a protective sleeve 4*a*, 4*b* surrounding portions of said tubes extending out of said element. A second side of said element opposed to said first side has a waffle shape formed by rows of bosses 8; 108 evenly spaced apart transversely of said element. The bosses of a row define projecting surfaces 9; 109 comprising substantially aligned portions of a cylinder, said cylinders having axes substantially coinciding with axes of said tubes 3.

6 Claims, 6 Drawing Figures



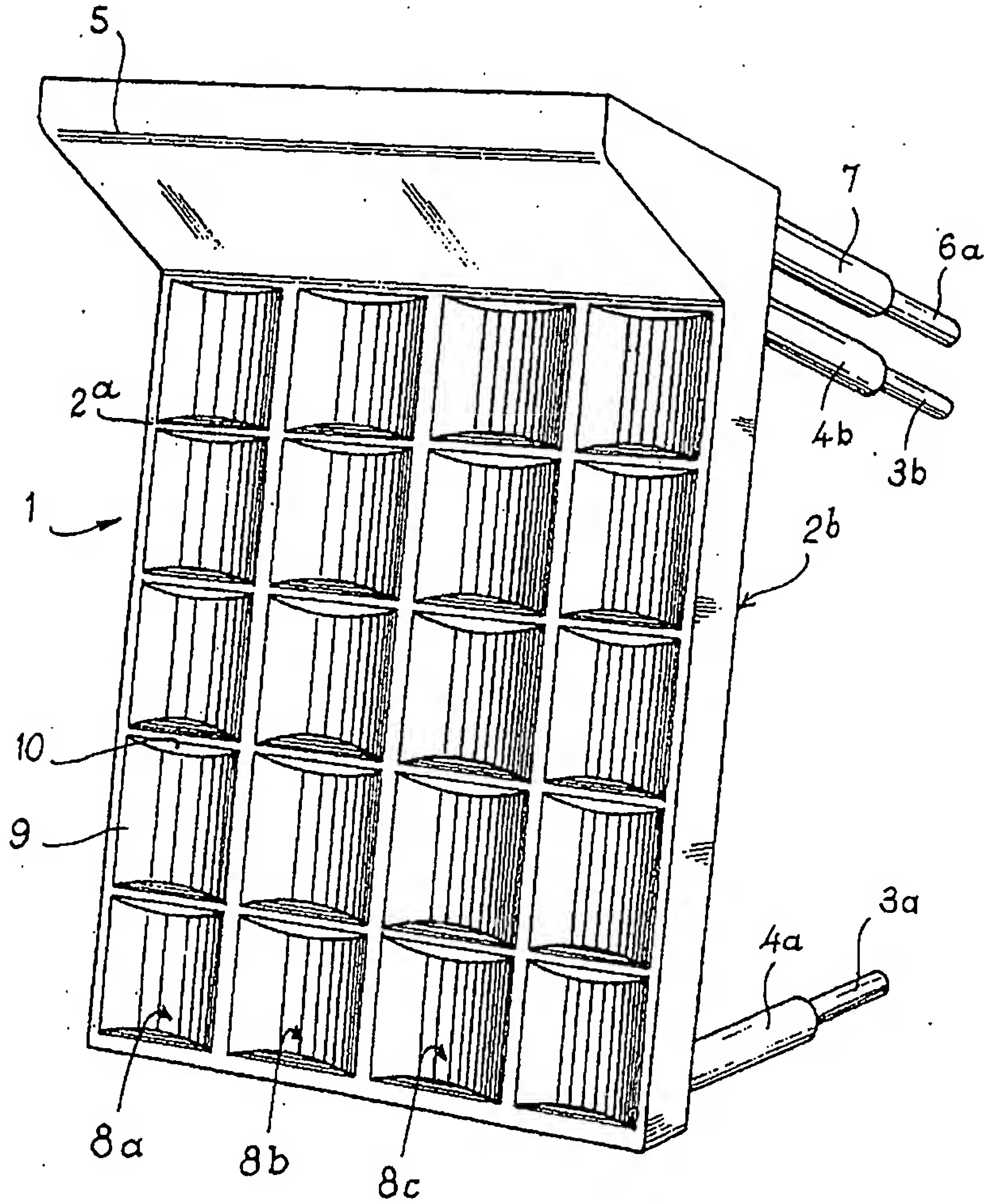
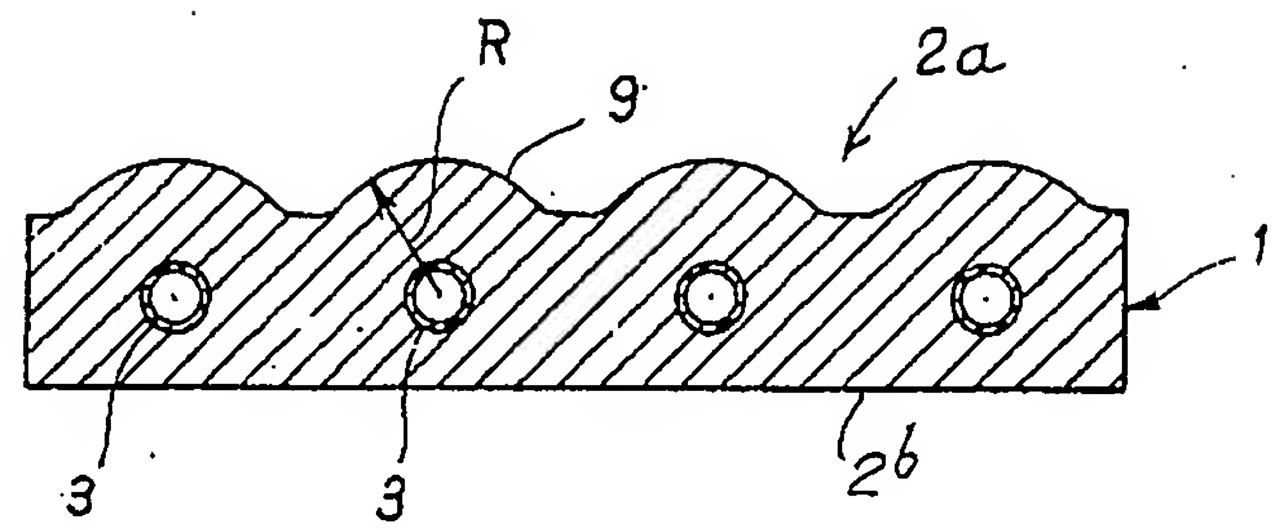


FIG. 1

FIG. 2



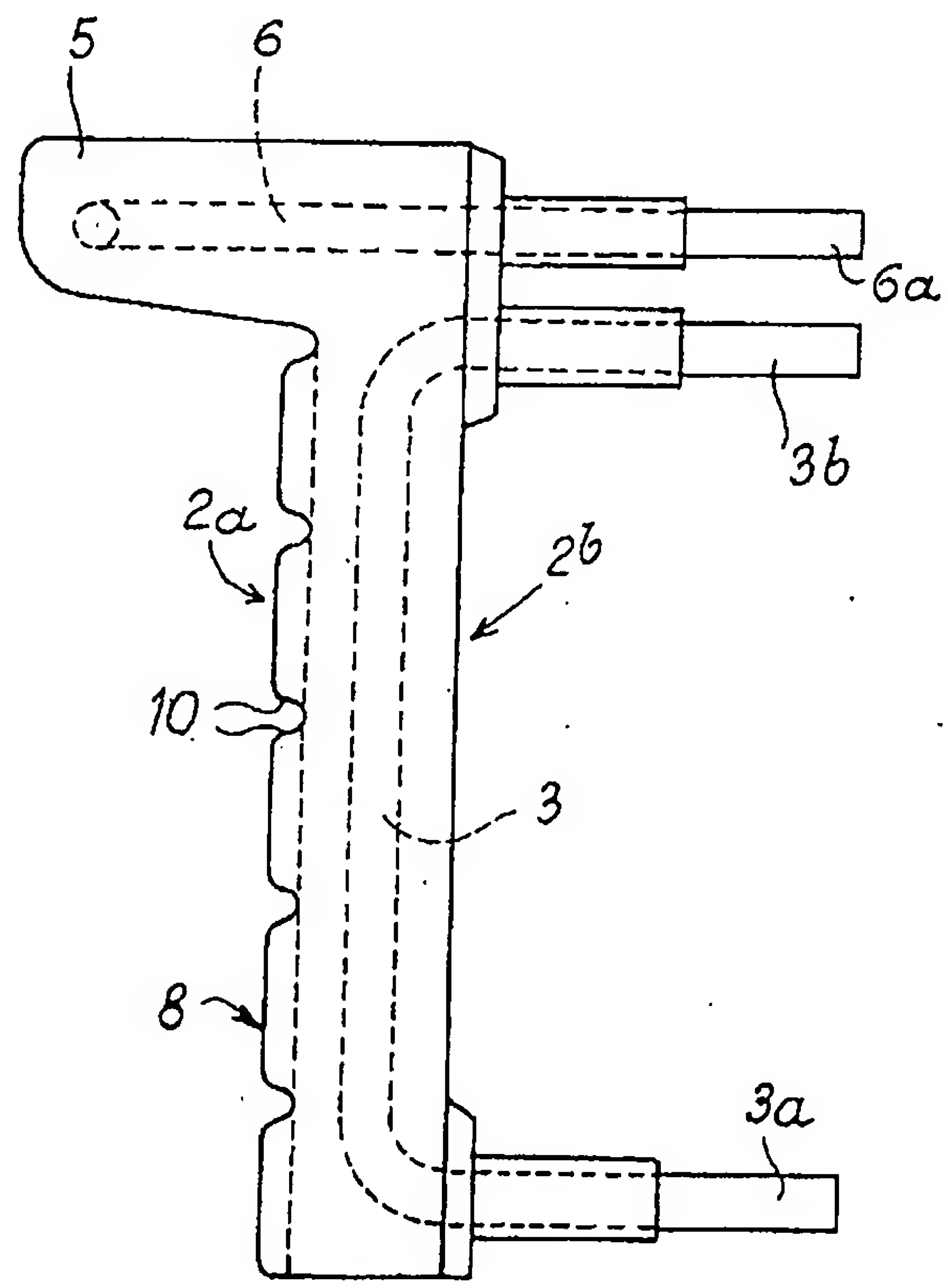


FIG. 3

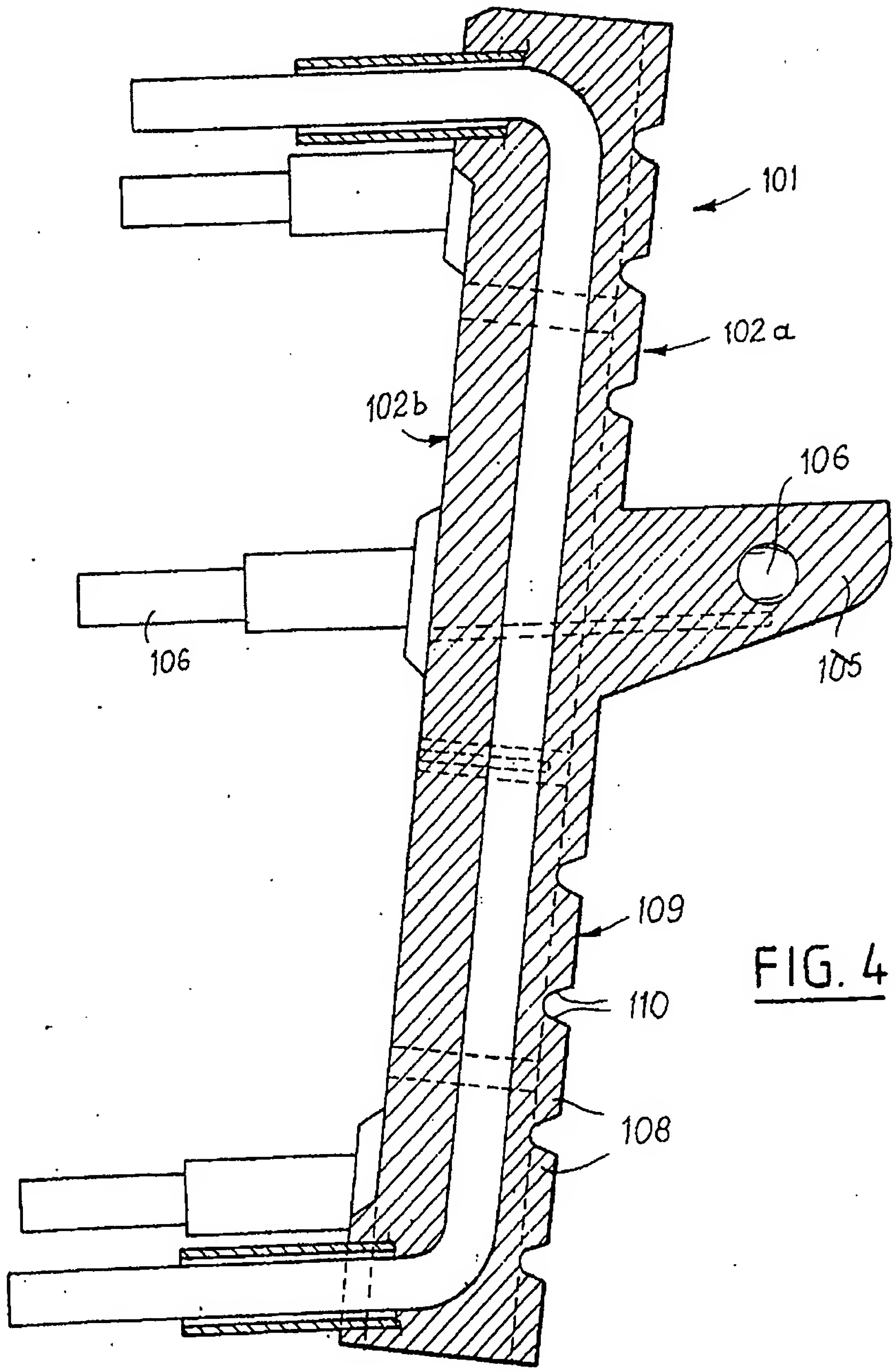


FIG. 4

FIG. 5

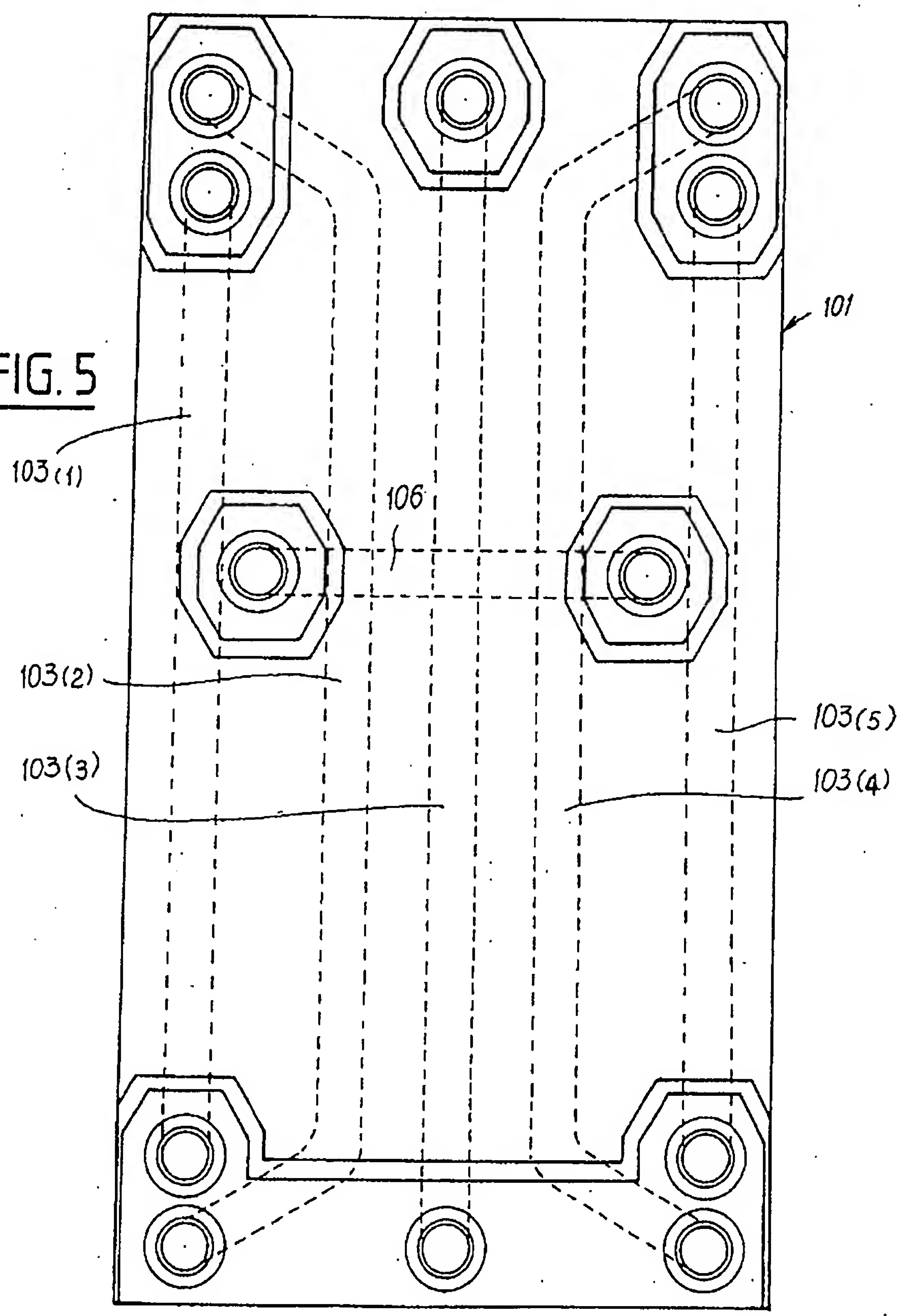
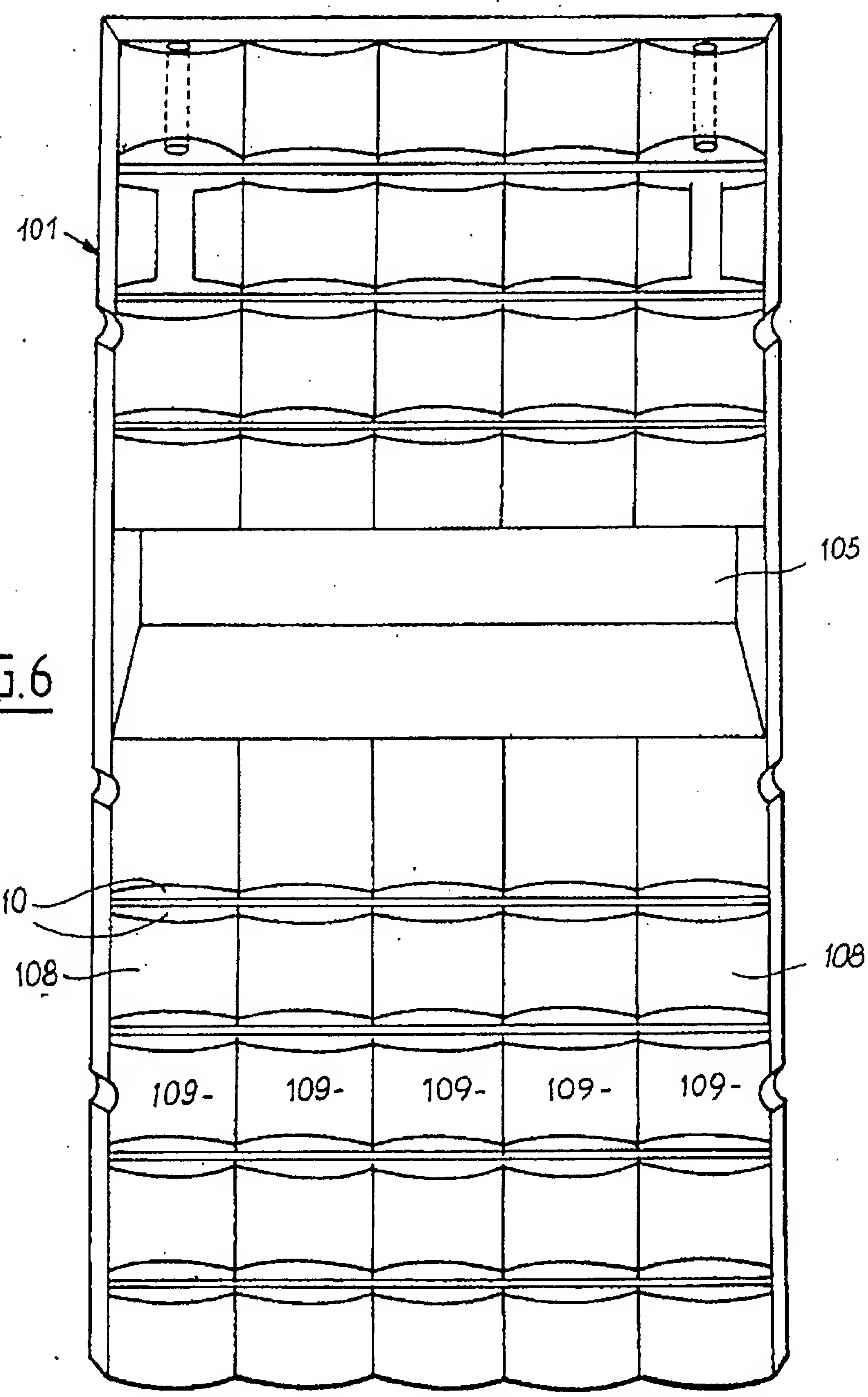


FIG. 6



COOLING PLATES FOR BLAST-FURNACES

This is a continuation of application Ser. No. 653,130, filed Sept. 21, 1984, which was abandoned upon the filing hereof.

The present invention relates to cooling plates for blast-furnaces.

These cooling plates are elements disposed against the inner side of the armour and perform a double function of cooling the refractory lining and providing a screen for the passage of the heat flow toward the armour.

The use of such cooling plates disposed between the inner wall of the armour and the refractory lining has been rendered necessary owing to variations in the heat flows involved in modern techniques for working blast-furnaces; these variations may be localized, rapid and aleatory with respect to time.

The cooling plates are formed by cast iron elements through which extends within their thickness a network of tubes in which flows a cooling fluid, usually water. These cooling tubes extend out of one side of the cooling plates and extend through the armour on the outside of which they are connected to cooling tubes of an upper or lower adjacent plate. The tubes connected in this way determine circulation lines of the fluid rising in a substantially vertical plane along the wall of the blast-furnace these lines being connected to an exterior fluid circulating and cooling circuit.

The cooling plate must be so designed as to:

resist thermo-mechanical deformations resulting from high heat flows;

ensure a good thermal exchange with the refractory lining, which implies disposing on the hot side shapes which facilitate an effective hooking of the refractory.

Now, cooling plates known up to the present time did not give full satisfaction as concerns these conditions and had defects which resulted, owing to repeated thermal stresses, in cracks within their thickness and, consequently, in a risk of leakages of the heat-carrying or exchanging fluids inside the blast-furnace, and in a mechanical stress in the cooling tubes in the region where they extend out of the cooling plates and extend through the armour.

In order to overcome these difficulties, there has been described in the patent No. FR 2 493 871, the application of which forms the priority basis for U.S. Pat. No. 4,437,651, a cooling plate formed by a cast iron element having a substantially parallelpiped shape in which are embedded longitudinal tubes disposed parallel to one another, these tubes leading out of the plate on the same main side thereof, respectively at the upper and lower parts of the cooling plate, in a protective sleeve, one of the original features of which resides in the waffle shape of the side opposed to that from which the cooling tubes extend.

The present invention concerns an improvement in this type of plate for the purpose of increasing the reliability of operation, in particular owing to an improved equilibrium of the thermo-mechanical stresses produced within the cooling plate.

The present invention therefore provides a cooling plate formed by a cast iron element which has substantially the shape of a parallelpiped and in which are embedded longitudinal tubes which are disposed vertically and parallel to one another, said tubes extending out of the same side of the plate, the side of the plate

opposed to that from which the cooling tubes extend having a waffle shape, wherein the waffling is formed by rows of bosses which are transversely evenly spaced apart, the bosses of one row defining projecting surfaces including portions of a cylinder whose axes are in longitudinal alignment and substantially coincide with the axes of the longitudinal tubes.

According to a modification, the inlets and/or the outlets of some longitudinal tubes are transversely offset relative to the longitudinal parts of said tubes, and are preferably located in the vicinity of the corners of the plate.

The invention will be described hereinafter in more detail with reference to the accompanying drawings which are given merely by way of example.

In the drawings:

FIG. 1 is a perspective view of a cooling plate according to the invention corresponding to a particular application concerning the last row of a "stave-cooler" system;

FIG. 2 is a cross-sectional view of the plate shown in FIG. 1, approximately in the middle of this plate;

FIG. 3 is a side elevational view of the plate shown in FIG. 1;

FIG. 4 is a sectional view of a plate according to a modification, and

FIGS. 5 and 6 are respectively elevational views of the two sides of the plate shown in FIG. 4.

In FIG. 1, the cooling plate 1 is viewed from its side *2a* which faces the interior of the blast-furnace and receives the refractory lining. Extending out of its opposite side *2b* are the inlets *3a* and outlets *3b* of longitudinal cooling tubes 3 which are embedded in the body of the plate 1. The ends *3a* and *3b* of each cooling tube extend out of the plate 1 at the upper and lower parts respectively through sleeves *4a* and *4b* which are embedded within the thickness of the iron of the cooling plate and also serve to fix the latter to the armour (not shown) of the blast-furnace.

The cooling plate 1 comprises, in its upper part, a lip 5 cooled by a transverse tube 6 which is disposed horizontally and which has an inlet end *6a* in the vicinity of the outlet *3b* of the tube 3, this outlet end being also surrounded by a sleeve 7 having one end embedded in the cooling plate. The cooling plate 1 has on its side *2a* a group of bosses *8a*, *8b*, *8c*, etc. which are identical and spaced apart transversely and aligned longitudinally so as to constitute rows.

These distinct bosses have external surfaces 9 which project from the side *2a* of the plate in the shape of portions of a cylinder. The transversely extending end surfaces 10 of these bosses are beveled. The axes of the portions of a cylinder constituting the surfaces 9 are longitudinally aligned, while the confronting transversely extending surfaces 10 of two adjacent bosses form a transverse V-section groove. As can be seen in FIG. 2, the cooling tubes 3 are embedded in the body of cast iron plate 1 and their axes coincide with the axes of the cylindrical surfaces 9 forming the bosses, so that they are placed in the regions where the thickness of the cross-section of the plate is maximum.

FIG. 3 clearly shows the V-section defined by the confronting transversely extending surfaces of two adjacent bosses. Also seen in FIG. 3 is the longitudinal path of the cooling tube 3 interconnecting the inlets *3a* and outlets *3b*. When this plate is in position in the blast-furnace, the tubes 3 are substantially vertical, while the transverse cooling tube 6 of the lip 5 is placed

substantially horizontally. The distance between the axes of the tubes shown in FIG. 1 may be varied while making sure that the axis of the tube 3 coincides with the axis of the part-cylindrical portion constituting the surface 9. The tube 3 is thus surrounded by a constant thickness of iron equal to the radius R in which a temperature gradient can be established for achieving an equilibrium of the thermo-mechanical stresses produced by the thermal exchange between the heat flow issuing from the interior of the blast-furnace and the cooling tubes embedded within the cooling plate

In the modification shown in FIGS. 4 to 6, the illustrated plate **101** has a lip **105** located in its central part in which a horizontally extending transverse tube **106** is disposed. It has on its side **102a** facing the interior of the blast-furnace, five rows of bosses **108** defining, as before, portions of a cylinder **109** and separated by beveled parts **110**. Five longitudinal cooling tubes **103(1)**, **103(2)**, **103(3)**, **103(4)** and **103(5)** correspond to these five rows of bosses. The inlet and the outlet of the central tube **103(3)** are disposed in the vertical plane of symmetry of the plate. On the other hand, the inlets and outlets of the other tubes are grouped in the vicinity of the corners and in the vicinity of the longitudinal edges of the plate. This is achieved, for example, by bending the end portions of the tubes **103(2)** and **103(4)** so as to bring them respectively below and above the inlets and outlets of the end tubes **103(1)** and **103(5)**.

This arrangement is particularly advantageous since it permits an increase in the cooling in the region of the corners of the plates which is usually particularly vulnerable.

What is claimed is:

1. In a cooling plate comprising a cast iron element having substantially the shape of a parallelpiped, embedded longitudinally extending tubes disposed vertically and parallel to one another and extending out of said element on a first side of said element, and a protective sleeve surrounding portions of said tubes extending out of said element; the improvement in combination therewith wherein a second side of said element opposed to said first side has a waffle shape, formed by rows of bosses evenly spaced apart transversely of said element, the bosses of a row defining projecting surfaces comprising substantially aligned portions of a cylinder, said cylinders having axes substantially coinciding with axes of said longitudinally extending tubes.

2. A plate according to claim 1, comprising beveled surfaces defining said bosses along transversely extending ends of said bosses, confronting beveled surfaces of two adjacent bosses defining a V-section groove extending transversely of said element.

3. A plate according to claim 1, wherein some of said tubes have inlets and outlets which are laterally offset relative to longitudinally extending parts of said some tubes.

4. A plate according to claim 2, wherein some of said tubes have inlets and outlets which are laterally offset relative to longitudinally extending parts of said some tubes.

5. A plate according to claim 3, wherein said inlets and said outlets of said some tubes are grouped together in a region located in the vicinity of each of the corners of said element.

6. A plate according to claim 4, wherein said inlets and said outlets of said some tubes are grouped together in a region located in the vicinity of each of the corners of said element.

* * * * *